Consultant Management Estimating Tool

Final Report

For New York State Department of Transportation

Prepared by Principal Investigators

Neville Parker, City College of New York

Trefor Williams, Center for Advanced Infrastructure and Transportation (CAIT), Rutgers University

Rutgers Center for Advanced Infrastructure and Transportation

the City College of New York

Page intentionally blank

introduction

The New York State Department of Transportation regularly contracts with engineering consultants for design services for some of their capital improvement projects. The contracts are administered through their Consultant Management Bureau, which includes establishing the scope of work for a project and preparing an independent staffing estimate for the design effort involved.

Because the department places a strong emphasis on fulfilling their responsibility to negotiate reasonable design staffing hours with consultants as part of the department's consultant acquisition process, it was decided to create an independent resource estimating tool.

This report outlines the steps taken to produce a resource estimating tool that can be used to estimate a reasonable design effort based on certain characteristics that are inherent for each of the department's projects.

These characteristics were gathered and evaluated by a technical working group (TWG) comprising of NYSDOT and FHWA personnel in collaboration with the University Transportation Research Center (UTRC)

Based on expert opinion, the following project characteristics were established and evaluated:

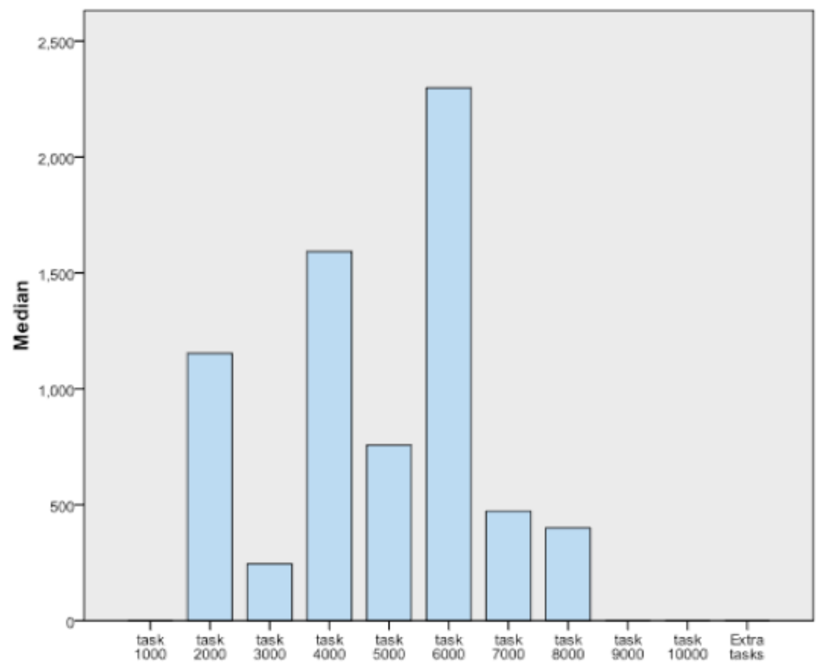
1. Complexity
2. Project type
3. Number of sub-consultants
4. Construction costs
5. Number of lanes
6. Number of plan sheets
7. State Environmental Quality Review (SEQR) classification
8. National Environmental Policy Act (NEPA) classification
9. Predominant bridge type
10. Number of bridges
11. Highway classification
12. Length of project

The goal of this project was to produce a computer tool that can be used by NYSDOT personnel to find historical information about the design hours required for NYSDOT highway and bridge projects that are similar in character. The developed Microsoft Access database allows users to search for data about projects that match the characteristics of a new project to help in negotiations with design consultants. Topics to be discussed in this final report include the data collection efforts, the analysis of the available data, and the estimating tool developed using Microsoft Access.

Data Collection and Analysis

NYSDOT provided hourly staffing data from 73 past projects, from which a spreadsheet of consultant design hours for said projects was developed. Upon examination of the data, it was found that 64 projects had enough data to record hours associated with task levels outlined in the department's base scope of services (BSOS). The spreadsheet also included several factors that influence the number of design hours. These were identified by the project TWG and were included in the project for analysis purposes. Variables included the project complexity, the type of project, the total cost of the project, and the number of plan sheets.

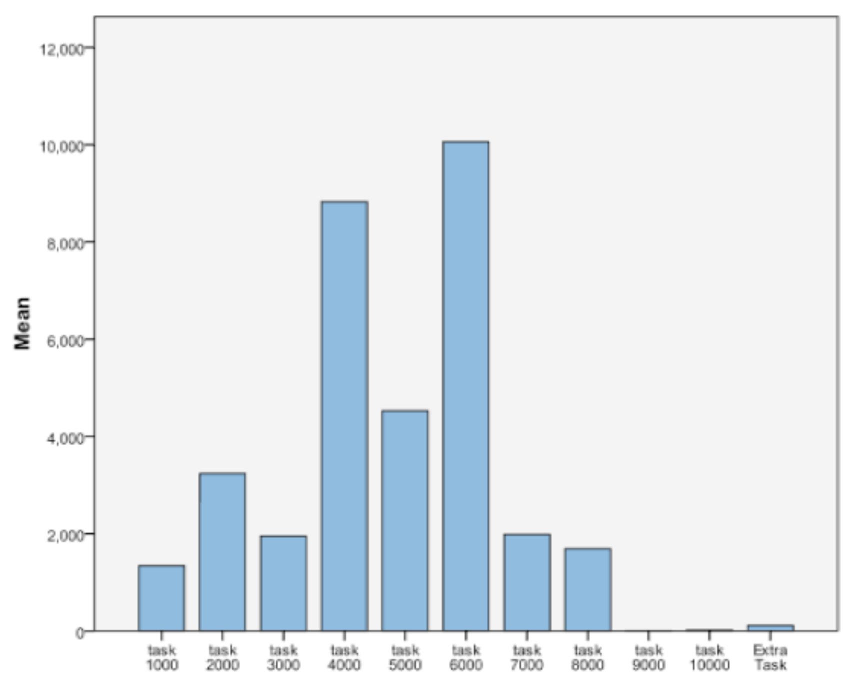
Figure 1. Median Values for Design Hours



Statistical Analysis of the Collected Data

Figure 1 shows the median values found for the various design functions, and Figure 2 shows the mean values found for the design functions. The 1000 level tasks are planning, 2000 tasks are design survey, 3000 are right-of-way surveys, 4000 tasks are preliminary design, 5000 tasks are in the area of socio/environmental impacts, bridge design is 7000, and 8000 are management tasks. It was noted that the highest values were in the 6000 category, which is final design.

Figure 2. Mean Values for Design Hours Correlation Analysis



Correlation Analysis

A correlation analysis was conducted to determine the relationship between the total project hours and other project variables including the number of sub-consultants, the number of plan sheets, the total project cost, and the project complexity. The Pearson correlation coefficient was calculated using the SPSS statistical software (Sheskin 1997). The coefficient describes the linear relationship between variables. The coefficient can take any value between -1 and +1. A zero coefficient means the variables are not correlated. Coefficients of +1 mean the variables are completely correlated. Values of -1 mean variables are perfectly negatively correlated, where as one variable increases, the other decreases. Table 1 shows the correlation table generated for the project data. The table shows that the total project hours have statistically significant positive correlations with the total project cost, the total number of plan sheets, and the number of lanes. The number of sub-consultants is also highly correlated; however, the expert opinion of the TWG indicates that the number of sub-consultants is not an independent variable that should be included in further analysis because it is dependent on the number of estimated design hours, and requires D/MWBE participation and specialized services.

Table 1. Correlations

		Total Hours	Const. Cost	No. Plan Sheets	Length (mi.)	No. Lanes	No. Subs
Total Hours	Pearson Correlation	1	.838 **	.535 **	.345	.495 **	.516 **
	Sig. (2-tailed)	—	.000	.009	.062	.005	.000
	N	69	38	23	30	31	49
Construction Cost	Pearson Correlation	.838 **	1	.750 **	.182	.263	.333
	Sig. (2-tailed)	.000	—	.000	.395	.204	.054
	N	38	40	25	24	25	34
No. Plan Sheets	Pearson Correlation	.535 **	.750 **	1	.172	.080	.116
	Sig. (2-tailed)	.009	.000	—	.556	.786	.637
	N	23	25	25	14	14	19
Length (mi.)	Pearson Correlation	.345	.182	.172	1	.191	-.079
	Sig. (2-tailed)	.062	.395	.556	—	.304	.694
	N	30	24	14	31	31	27
No. Lanes	Pearson Correlation	.495 **	.263	.080	.191	1	.547 **
	Sig. (2-tailed)	.005	.204	.786	.304	—	.003
	N	31	25	14	31	32	28
No. Subs	Pearson Correlation	.516 **	.333	.116	-.079	.547 **	1
	Sig. (2-tailed)	.000	.054	.637	.694	.003	—
	N	49	34	19	27	28	50

** Correlation is significant at the 0.01 level (2-tailed).

Regression Models

Regression was studied to determine if simple or multiple linear regression models could be used to provide accurate predictions of total project hours and then be incorporated in the developed estimating support tool. The object of linear regression is to use the linear relationship between a response (dependent) variable and factor (independent) variables to predict or explain the behavior of the response variable. For this project the response variable was the design hours, as well as other variables such as the project cost, and the independent variable was the number of plan sheets. Other factors that were considered but not included in the model were project type (e.g., new or rehabilitation project).

Development of Regression Models

To develop a linear regression equation, the stepwise equation-building technique and the backward elimination equation-building technique were employed. The stepwise procedure examines the significance of each input variable. Variables that are statistically significant are added to the regression equation. The order of insertion is determined by using the partial autocorrelation coefficient as a measure of importance of variables not yet in the equation (Draper and Smith, 1981). Depending on the significance of the input variables, the technique can yield a simple or a multiple regression equation. This technique is implemented in the SPSS statistical software package (Norusis, 1993). Using the stepwise procedure, all of the variables identified by the TWG were considered for inclusion in the model. The stepwise procedure examines the significance of each input variable. Variables that are statistically significant are added to the regression equation. One simple equation was produced that relates the total project hours to the project construction cost.

The backward technique was also used to develop regression models. It is a method for sequentially removing variables, which begins with a model containing all independent variables; the variables that change R^2 the least are then removed. Using this technique, multiple regression models were produced using several variables. It yielded a model that predicted total hours based on the number of plan sheets, the number of lanes, and the project length in miles.

Regression Models Using Consultant Data

Using analyzed data from 73 projects designed by consultants, several regression models were constructed with project cost, number of lanes, project length, and number of plan sheets as factor (independent) variables.

The database contained cases with missing data; in some instances this resulted in a lower number of independent variable combinations for use in model building. It is anticipated that as more data is collected the regression models can be recalculated so that other variable combinations can emerge as the "best" regression equation.

Several models have been studied. The two best performing models are shown in Table 2. R^2 is a measure of the performance of regression models. An R^2 of 1 indicates the model and the data are perfectly correlated. At this time it is recommended that equation one be employed as a predictor of total hours because it is the most parsimonious model and has the highest R^2 value.

State Designed Bridge Projects

Regression was also applied to bridge projects designed internally by the NYSDOT. These data were used to determine if a larger data set would result in higher R^2. The stepwise regression method was applied with 202 cases in the database used for analysis. The regression equation was found to be:

Total Hours = 519.249 + 93.408(No. of Plan Sheets)

The R value for this regression equation is 0.792 and the R^2 value is 0.628. This regression R^2 was similar to the R^2 results reported for the regression models using the consultant data.

Table 2. Regression Models for Consultant Data

Model Number	No. of Cases	Model Equation	R	R^2
1	22	Total Hours = (.001)Construction Cost + 8223.14	.830	.689
2	12	Total Hours = (28)No. Plan Sheets + (793.14)No. of Lanes – (1108.603)Length + 10593.607	.792	.628

Regression through the Origin

When using the regression equations derived from the consultant, it became apparent that the equation gave impractical predictions. In particular, if there were zero plan sheets, because of the constant in the regression equation, the model produced a positive number as the prediction. To prevent this it was decided to force the regression equation through the origin to ensure that when there were zero plan sheets, no design hours would be predicted. The best-performing model using the SPSS software when regression is forced through the origin was found to be:

Total Hours = 95.039(No. of Plan Sheets)

Based on this analysis, it was decided to use this simple relationship between the total hours and the number of plan sheets in the consultant management decision support tool. However, the database has been programmed to continuously recalculate the regression equation every time there is a search so that new data is automatically included in the calculation of the simple regression model. It is anticipated that as more data is added, the regression predictions will become more accurate.

Other Modeling Techniques

The possibility of employing other modeling techniques to provide predictions of the total project design hours was explored. Data visualization, data mining, and Monte Carlo simulation were studied to determine if useful predictions could be produced. Unfortunately, the limited amount of consultant data available did not allow any useful models to be developed. It is recommended that as the database is expanded and more project information is available, these methods be restudied.

Development and Implementation of the Consultant Management Estimating Tool

A Microsoft Access database was developed to provide a tool for retrieving historical information about consultant hours from past projects, and to produce predictions of total hours required using the regression modeling technique studied in the data analysis phase of the project. The project data collected formed the initial database for the estimating tool.

The estimating tool was designed to have a hierarchical structure of menus to provide an easy-to-use interface. The functions and format of the database were developed in consultation with the TWG. The users' manual for the consultant management estimating tool is attached as an appendix to this report. The estimating tool has the following major functions:

- Search projects. This function allows data about projects to be retrieved from the database. Users can search using matching criteria to find historical projects similar to a new project they are initiating.
- Edit and view data. This function allows records to be modified and updated.
- Insert and automatically import data. Two Microsoft Excel spreadsheet templates were developed that can be filled in to record estimated and actual hours, which are automatically uploaded to the estimating tool.
- Estimate of total hours using regression analysis. This function provides a method of obtaining predictions of the total project hours required based on the number of project plan sheets. Users have the ability to filter the projects used for the regression calculation. The equation is not fixed but is recalculated continuously based on the filter settings and the projects contained in the database. Therefore, the prediction is expected to become more accurate as projects are added to the database.
- Overview graphs. The overview graphs provide users with pie charts that describe the characteristics of projects contained in the database.

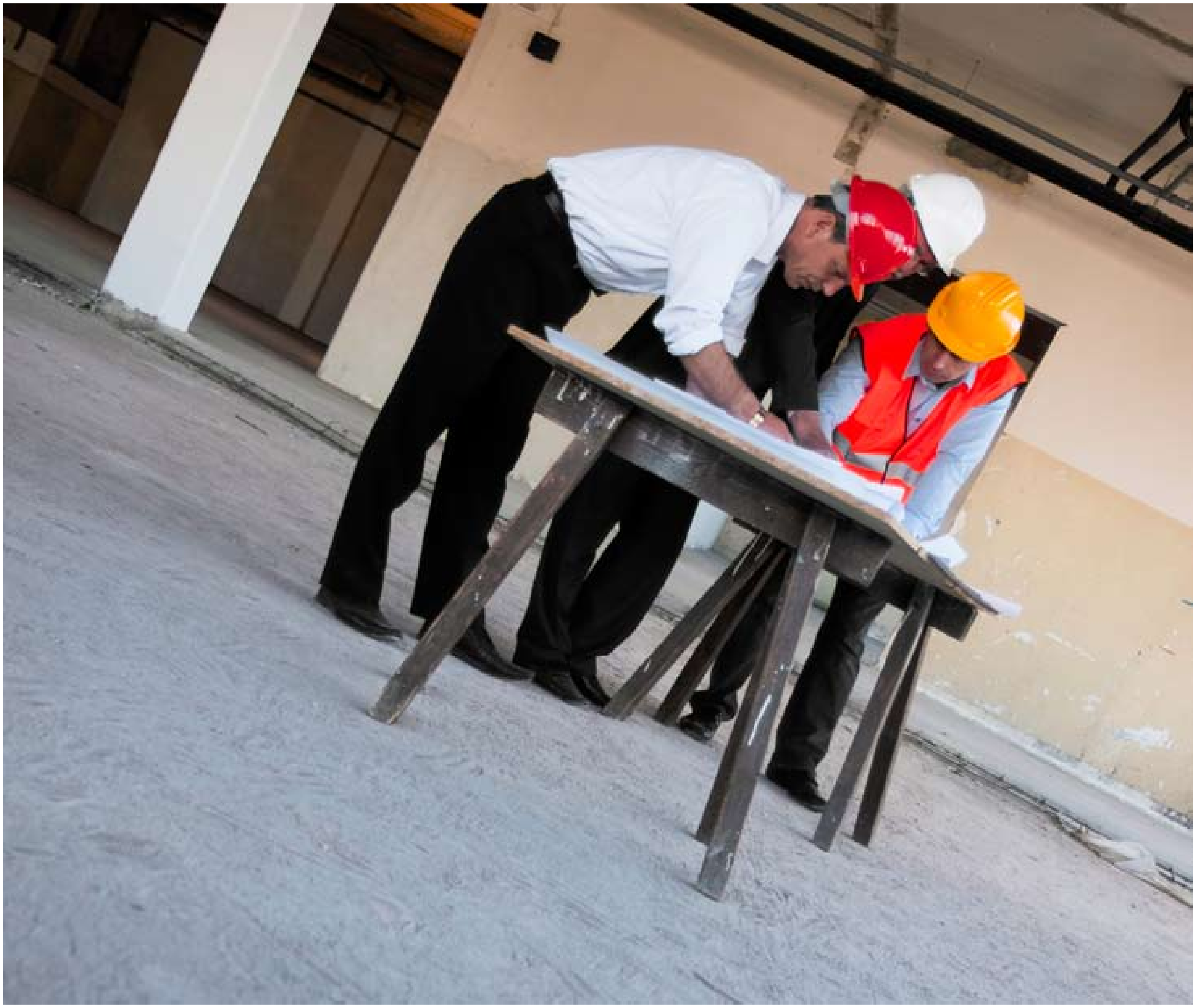
The consultant management estimating tool was tested extensively in the summer of 2011 by the NYSDOT. This provided the opportunity to thoroughly debug the operations of the tool and make modifications and enhancements based on TWG suggestions.

Conclusions and Suggestions for Further Research

The estimating tool was developed as a practical application to provide enhanced information to NYSDOT consultant management personnel. Extensive consultations with the TWG have allowed for the production of a useful tool that conforms to the needs of the NYSDOT.

Several modeling techniques were studied to develop predictive models of total design hour requirements. Due to the relatively small amount of data that was available, a simple relationship between the number of plan sheets and the total hours for the established regression model were used. More data will be added to the consultant management estimating tool as it is used by the NYSDOT. It is suggested that at some future date it will be useful to:

- Re-evaluate the parameters used in the regression model. As more data becomes available, a more sophisticated multiple regression model may yield improved predictions.
- Consider other modeling techniques. With more project data it may be possible to develop accurate predictions using other data mining techniques, like machine learning and simulation methods such as the Monte Carlo technique.



Acknowledgements

We would like to acknowledge James Klotz and all members of TWG for providing their valuable insights during the course of the project.

References

Draper, N. R. and Smith, H. (1981) *Applied Regression Analysis,* 2nd Ed., Wiley, New York.

Norusis, M. J. (1993) *SPSS for Windows Base System User's Guide, Release 6.0*, SPSS, Inc., Chicago, IL.

Sheskin, David J. (1997) *Handbook of Parametric and Non-Parametric Statistical Procedures.* CRC Press, Boca Raton, FL.

RUTGERS
Center for Advanced Infrastructure
and Transportation

Rutgers, The State University of New Jersey
100 Brett Road
Piscataway, NJ 08854-8058

the City College of New York

University Transportation Research Center
Marshak Hall - Science Building, Suite J-910
The City College of New York
138th Street & Convent Avenue
New York, NY 10031